Crossbreeding systems and appropriate levels of exotic blood: Examples from Kilifi Plantations

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Introduction

In Africa, crossbreeding has resulted in good improvements in production of milk and meat, especially when supplemented with adequate management levels in terms of nutrition, disease control etc. The effect of crossbreeding has, however, also been disastrous, especially in the smallholder sector where less attention is paid to matching the genotype to the environment. Most smallholders practise systems of upgrading indigenous breeds to higher exotic grades without following a defined crossbreeding programme. Kilifi Plantation's crossbred dairy herd that is kept in the subhumid coastal lowland of Kenya is a good example of a commercial farm that is able to enjoy the benefits of supplementing crossbreeding with good management. In this herd, the Ayrshire (A), Brown Swiss (B) and, most recently, the Friesian (F) have been used for crossbreeding with Sahiwal (S) cattle for commercial dairy production. Data generated from this herd have been analysed in recent years with the aim of comparing various crossbred genotypes, estimating crossbreeding parameters and predicting performance of crossbreeding systems. The experiences of Kilifi Plantations provide a rare opportunity for the preparation of a well-documented African case study illustrating the effect of different cattle crossbreeding systems and levels of exotic blood on productivity.

Genetic background

The basis of crossbreeding can be classified broadly into two types: additive and non-additive. The additive component is that which is due to the averaging of merit in the parental lines or breeds, with simple weighting according to the level of gene representation of each parental breed in the crossbred genotype (Swan and Kinghorn 1992). This additive component can be divided into individual and maternal additive genetic effects. The individual additive genetic effect is the contribution to offspring phenotype that is attributable to its own set of genes. Maternal additive genetic effects are defined as any contribution or influence on the offspring's phenotype that is attributable to its own dam (Maurer and Gregory 1990). Maternal effects can be classified into prenatal (e.g. cytoplasm of the ovum and uterine environment) and postnatal environment (e.g. milk production, method of rearing and/or mothering ability).

Heterosis is the non-additive effect of crossbreeding. It is the amount by which merit in crossbreds deviates from the additive component (Swan and Kinghorn 1992). Heterosis is usually attributed to genetic interactions within *loci* (dominance) and interaction between *loci* (epistasis). Heterotic effects can be classified into individual and maternal heterosis. Individual heterosis is the deviation (or superiority) in performance in an individual relative to the average value of the parental breeds, with maternal, parental or sex-linked effects playing no role. Maternal heterosis refers to heterosis in the population that is attributed to using crossbred instead of purebred dams and occurs due to the dam itself possessing heterosis.

Dominance

The level of allelic heterozygosity is expected to increase where an individual's parents come from two different breeds. This is because the individual's genes are sampled from two breeds which differ in their gene frequency. Crossbreeding leads to an increase of the frequency of heterozygous *loci*, which better equip the individual to perform well under varying or stressful environments. It is normally assumed that a linear relationship exists between dominance and the degree of heterozygosity (Dickerson 1973). Dominance is therefore expected to be favourable.

Epistasis

To carry out respective tasks, genes must co-operate well. In purebred animals, this has been made possible by several generations of selection. During crossbreeding, genes must interact with other genes from other *loci* that are derived from different breeds. Crossbred animals may therefore be 'out of harmony with themselves' and certain genes may suppress the effect of other genes. As opposed to dominance, epistasis has a negative effect in crossbred animals. The breakdown of favourable epistatic interactions between genes on different *loci* (recombination loss) has been suggested as one of the reasons for a drastic deterioration in performance in some crossbred generations (Dickerson 1973).

Kilifi Plantations

Location and climatic conditions

The ranch is located in Kilifi District, 60 km North of Mombasa, Kenya. The region has an average annual rainfall of 1000 mm and relative humidity of 80%. The main wet season starts at the end of March. The rain is heavy in April and May, and decreases gradually until October. The secondary wet season starts towards the end of October and lasts until December or January. The highest temperatures (monthly average 30ºC) occur during January and February, while the lowest temperatures (monthly average 22ºC) occur in June and July (Jaetzold and Schmidt 1983).

Short history and mating systems

The herd was established in 1939 from a continuous two-breed rotational crossbreeding system involving the Sahiwal (S) and Ayrshire (A) breeds; it was transferred from Machakos in the eastern province of Kenya to Kilifi in 1963. The A bulls were mated to cows with a breed content of 67% S:33% A (Sr) and S bulls were mated to 67% A:33% S (Ar) cows. These cows were sometimes mated back to bulls of the same breed as their sires to produce genotypes of 83% S:17% A or 83% A:17% S (Figure 1). In the mid 1970s, the Brown Swiss (B) breed was introduced to the rotation and first mated to the rotation cows to produce genotypes with breed compositions of 50% B:33% S:17% A or 50% B:33% A:17% S. In accordance with the rotation, these crossbred cows were usually mated to A and S bulls, respectively, though they were sometimes mated to B or S or A bulls. That is, the rotation was not followed strictly and several genotypes, such as those shown in Plate 1, were generated with a minimum of 8% and maximum of 83% of genes from any one breed.

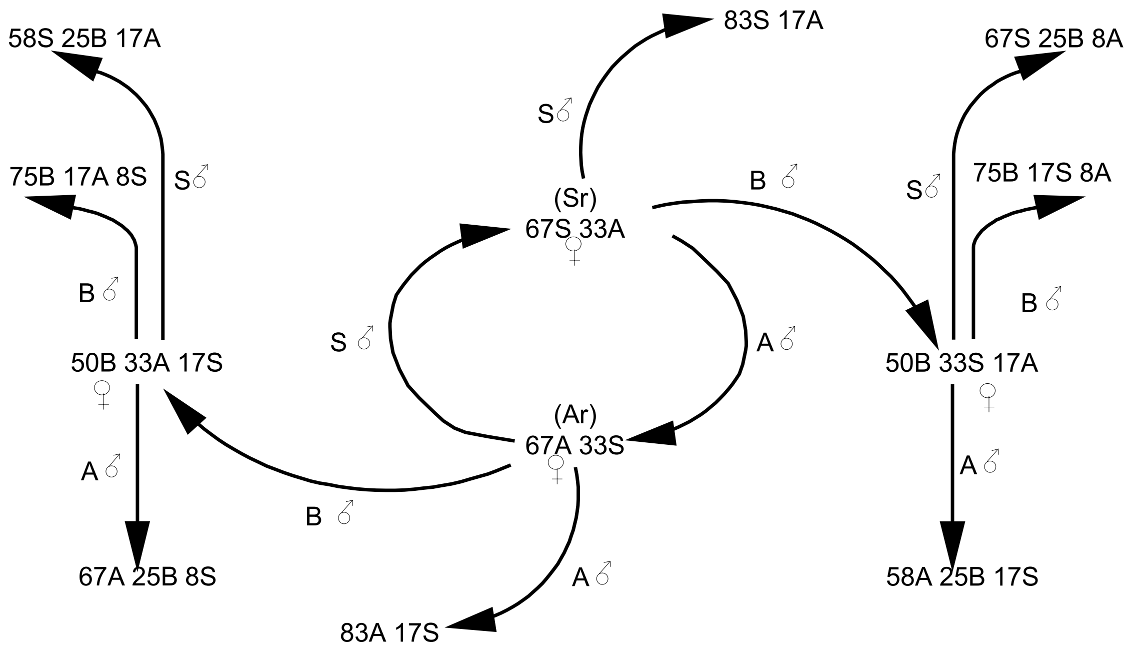


Figure 1. Mating systems before the introduction of the Friesian breed. A = Ayrshire; B = Brown Swiss; S = Sahiwal; r = stabilised two-breed rotation. Numerical values indicate the percentage contribution of each breed to the genotype.

Plate 1. Crossbred cows at Kilifi Plantations having different proportions of A, B, F and S genes; left - 33% A:33% B:33% S; right - 50% B:17% A:33% S.

In the early 1990s, a fourth breed, the Friesian (F), was introduced and mated to the above genotypes with the aim of replacing the A breed in the crosses. Plate 2aa shows an example of an F-sired crossbred cow. Generally, matings are by artificial insemination (AI). The A, F and S semen is from the Kenya National AI Service, while B semen is imported from the USA. In cases where the cows do not conceive after two AI services, they are grazed together with crossbred bulls, such as that shown in Plate 2b, bred in the Kilifi herd for at least two natural services.

Plate 2a. A crossbred cow at Kilifi Plantations with the gene proportion 50%F:17% B:17% A:17% S.

Plate 2b. A crossbred bull at Kilifi Plantations with the gene proportion 75% B:17% A:8% S.

Experimental evidence

From 1975 until the present time, data generated by this herd have been analysed and several papers have been published. With the development of analytical models, there has been a tendency to switch from the traditional use of fixed models to the use of animal models. Kimenye and Russell (1975), Trail and Gregory (1981), Thorpe et al. (1994) and Kahi et al. (1995) used a fixed effects model to compare the various crossbred genotypes that had been generated at the time of analysis. Mackinnon et al. (1996) and Kahi et al. (2000a, 2000c) used an individual animal model that accounted for all additive genetic relationships between animals. They used this model to estimate the breed cross means, which were then regressed on co-variables for breed additive and non-additive effects to estimate crossbreeding parameters. These data have also been used to compare crossbreeding parameters estimated using genetic models that ignore epistasis effects, assume the effects to be equal for all breed combinations and estimate these effects for each breed combination (Kahi et al. 2000a).

Crossbreeding systems

In a fixed effect analysis of preweaning data, Kahi et al. (1994) classified the 12 genotypes represented in the study into five mating systems, namely: Sr and Ar, two-breed rotation; S × Sr and A × Ar, two-breed backcross; B × Sr and B × Ar, three-breed cross; B × (B × Sr) and B × (B × Ar), three-breed backcross; and A × (B × Sr), S × (B × Sr), A × (B × Ar) and S × (B × Ar), three-breed rotation. The significance of specific differences between these systems was determined. They reported very little variation among the systems for calf performance. It was concluded that no emphasis should be given to preweaning performance when selecting among these systems, but that decisions should be based on relative lactation and reproductive performances.

Based on estimated crossbreeding parameters, Mackinnon et al. (1996) predicted milk yield of four crossbreeding systems, namely: the two-breed rotation $(AS)_{Rot}$; three-breed rotation $(ABS)_{Rot}$; first cross (B × S); and ABS-based three-breed synthetic. Results indicated that the predicted performance of the BS first cross system was closely rivalled by the three-breed rotation and the three-breed synthetic, mainly because of the high degree of heterozygosity maintained in these systems. These results were confirmed by Kahi et al. (2000b, 2000c) in an analysis that included data from the F-sired crossbreds. In that study, the array of crossbreeding systems was large and included first cross (F × S); two-breed rotation $(AS)_{Rot}$; three-breed rotation $(BFS)_{Rot}$; and two- (F and S), three- (B, F and S) and four-breed synthetic breeds based on equal and unequal contributions of the foundation breeds. Performance of cows under these crossbreeding systems and of the production systems in which it is necessary to keep dams that have low genetic potential were compared. These were the production systems based on the first cross and the rotations. The methods used and assumptions made are clearly documented by Kahi et al. (2000b). For milk yield and calving interval, the results showed that the first cross system was closely rivalled by the three-breed rotation and the synthetic. For profit per day of herd life, inferiority of the first cross was marked in a production system requiring replacements to be raised from within the system. This finding was contrary to the prevalent recommendation that the first cross is most suitable for dairy production in the tropics; a recommendation based on comparison of different gene proportions in static crossbreeding systems without due regard to the overall production system.

Levels of exotic blood

At Kilifi Plantations, there exists a wide array of crossbred genotypes, each with a certain proportion of genes from the A and S breeds (Kahi et al. 1995, 2000a, 2000c). Because of changes in the breeding decision, not all genotypes have genes from the B and F breeds. In all the genotypes they are represented in, they are not the only *B. taurus* breed; consequently, the possibility of quantifying the relationships between performance and proportion of either B or F is limited. Therefore, the A, B and F are classified together as *B. taurus*. Use of information from genotypes that only have the A as the *B. taurus* breed, resulted in trends in the relationships that were similar to those for the combined comparison; it was therefore decided to present results from the combined comparison. The means for each genotype are reported in detail elsewhere (Kahi et al. 2000a, 2000c) and will be summarised here in graphical form only. The relationship between performance and proportion of exotic genes may differ depending on the exotic breed used (Rege 1998). The relationship between preweaning performance and proportion of exotic genes was not quantified in this case study because of the small variation among the A, B and S breeds reported by Kahi et al. (1995).

Certain gene proportions are represented by a number of genotypes with varying numbers of observations (Kahi et al. 2000a, 2000c). They are, therefore, grouped together and their means estimated using the number of observations as weights. Figures 2 and 3 illustrate the relationships between the proportion of exotic genes and milk production and reproductive traits and economic traits, respectively. The results show a consistent reduction in the age at first calving with increasing levels of exotic genes up to 67% exotic inheritance. For lactation milk yield, there was considerable improvement when the percentage of exotic genes was increased. This supports findings that on average, the lactation milk yield normally remains approximately constant between 50 and 100% exotic inheritance. Lactation length increased with increasing exotic inheritance. Calving interval followed the pattern of lactation length (Figure 2) and was inconsistent with the literature, which has reported a decline in calving interval up to an exotic inheritance of 50%.

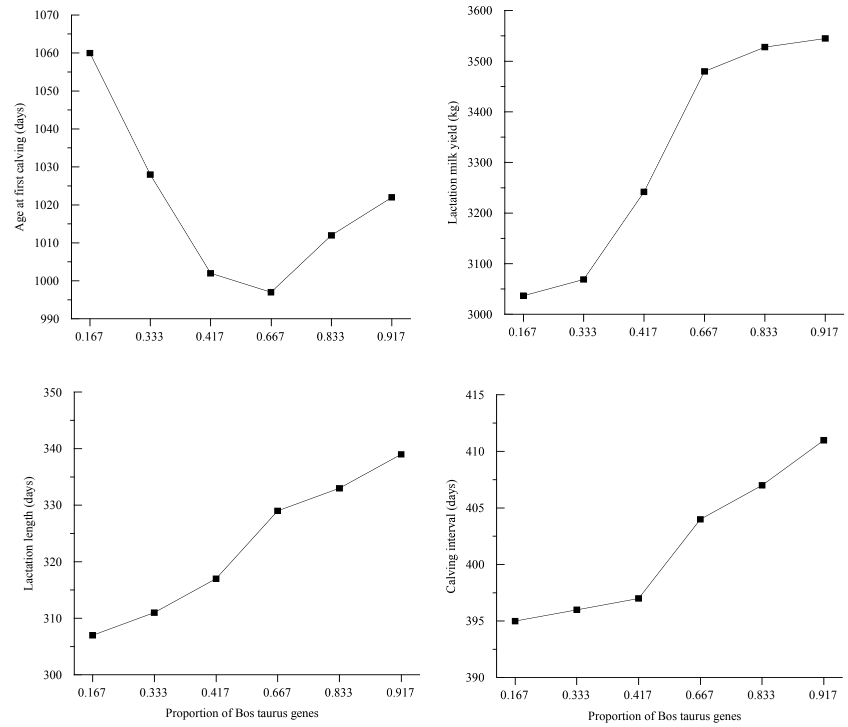
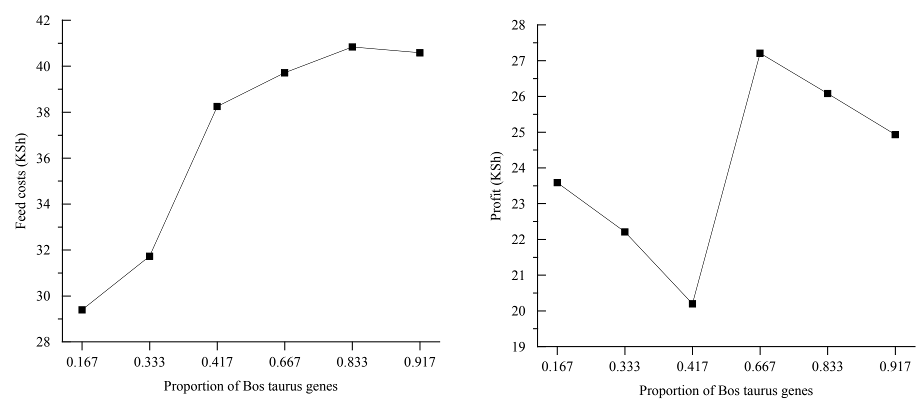


Figure 2. Relationships between the proportion of B. taurus genes and lactation and reproductive performance traits

For the economic traits, there is an increase in feed costs with increasing level of exotic genes up to about 80%. This is expected because of the linear relationship between feed intake and mature body weight, and compares very well with the relationship in Figure 2 for lactation milk yield. Higher milk yields are partly due to higher mature body weights. The trend in profit is an 'up and down' one as profits decrease with increasing level of exotic inheritance up to 42%, then increase to a peak at 67% after which a reduction is noticed (Figure 3). Differences between the trends in lactation milk yield and feed costs, and profit are interesting and clearly demonstrate that profit is an aggregate trait, which is influenced by many genes at many *loci*.



KSh = Kenya shilling; KSh 1 = US$ 0.02 in December 1997.

Figure 3. Relationship between proportion of Bos taurus genes and economic performance. All variables are expressed per day of productive herd-life.

Purebred animals are not represented in the Kilifi Plantation data; however, their performance and that of the F_1 cross between them can be predicted using estimated crossbreeding parameters. The performance of the purebred *B. taurus,* and F_1 cross between *B. taurus* and S was estimated as the mean performance of the three purebred *B. taurus* breeds and of the F_1 cross between these breeds and S, respectively. The trend in performance for the three gene proportions is depicted in Figure 4. The trait values are expressed relative to the trait values of the F_1 (50% *B. taurus* genes), which were set to 100. As can be seen for most traits, the trends were similar to those obtained in Figures 2 and 3. When the performance of the purebred S and *B. taurus,* and the F_1 cross between them is predicted by extrapolation and interpolation using Figures 2 and3, similar trends to those shown in Figure 4 are obtained.

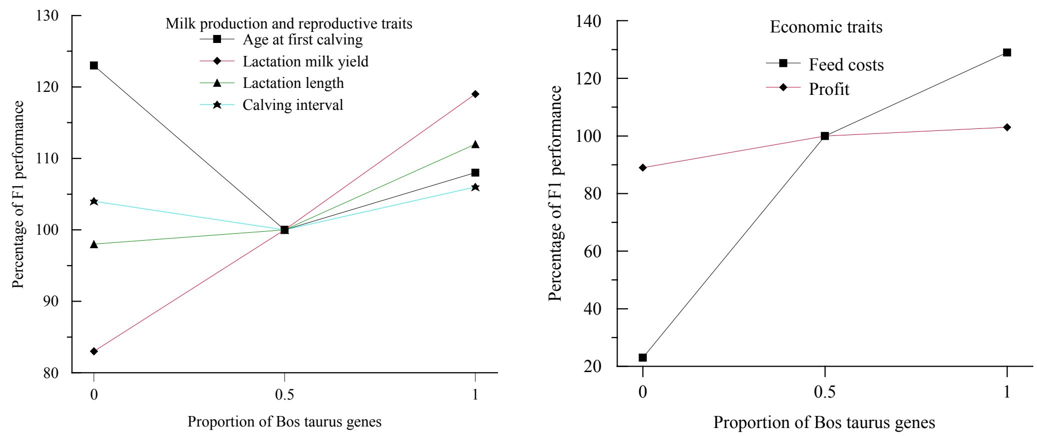


Figure 4. Relative values (F_1 = 100) of predicted means for the milk production, reproductive and economic traits.

Conclusions

Crossbreeding between highly productive and adapted breeds can improve overall performance. However, if crossbreeding is indiscriminate and uncontrolled, it may result in reduced productive advantage. In the starting phases of a crossbreeding programme, performance is always improved due to the heterotic superiority of the first cross. Thereafter, if the programme is not checked, the productive advantage may be reduced either because of recombination loss that leads to breakdown of the heterotic superiority in subsequent generations or upgrading to high levels of exotic blood without changing the environment. This leads to insufficient adaptation, which is manifested in the decline in performance. Cunningham and Syrstad (1987) reported a linear improvement in almost all performance traits up to the 50% *B. taurus* inheritance. Beyond 50%, there was a slight increase in calving interval, but no clear trend in the other traits. Madalena et al. (1990a; 1990b) found increases in performance for all milk, reproductive and calf traits up to 62.5% *B. taurus* inheritance, after which performance began to decline. In a comprehensive review of 80 reports from Africa, Asia and Latin America, Rege (1998) reported an improvement in milk yield when the proportion of exotic blood increased from 0 to 50% and a constant level between 50 and 100% exotic inheritance. A similar trend was observed for age at first calving. Lactation length increased over the entire range of exotic grades, although with 'up-and-down swings'. For calving intervals, the shortest were observed for animals with 50% exotic genes and were longer both for animals with lower or higher exotic inheritance.

Kilifi Plantations is one of the many examples in the tropics where exotic grades or pure exotics are being used successfully. Therefore, the generalisation that cattle with 50% exotic inheritance are best suited for dairying in the tropics needs to be reconsidered. The results described in this case study and information from the literature suggest that the appropriate levels of exotic blood and their effects on productivity depend on two factors:

1. the environment (especially disease control and nutritional level) in which the crossbred is performing (genotype x environment interactions).
2. the exotic and the indigenous breed in question (genotype× x genotype interactions).

Emphasis must be put on practical crossbreeding systems that are able to raise animal productivity from low to intermediate rather than on 'ideal' programmes, which are too difficult to be implemented and economically supported by the production environment.

Knowledge gaps

Although crossbreeding has been used successfully in Kilifi Plantations, there is still need for further work on crossbreeding if it is to be beneficial to a wider array of cattle owners. Areas that require further study include the following.

- Kilifi Plantations serves as a source of breeding material for production systems with low management levels in terms of nutrition and disease control. This could mean that crossbred genotypes that perform well under Kilifi Plantations' conditions might not perform as well in these systems. The major challenge, therefore, is to intensify efforts to recognise the diversity of tropical production systems with the aim of achieving a consensus on the appropriate crossbred genotype for each system.
- In crossbreeding, there has been a tendency to lump breeds together as either exotic or indigenous when quantifying the relationship between performance and gene proportions. If sustainable production is to be achieved, breeds must be evaluated exhaustively and matched to the levels of inputs. This calls for within-production system analyses to determine which exotic or indigenous breed should be used and what levels of exotic blood should be maintained in crossbred genotypes.
- Only one study compared the economic performance of different genotypes under the conditions at Kilifi Plantations. This is not enough bearing in mind the diversity in tropical animal production systems. There is, therefore, the need to study the economics of production by the different genotypes in the various production systems.
- In most situations, crossbreeding has been applied in isolation and in an indiscriminate manner. It should involve sire evaluation and selection with the aim of stabilising the crossbred population at the desired level of combination of different breeds. A question that would then have to be answered is how the desired combination could be continuously produced and utilised; this question centres both on genetic and logistic aspects.
- Utilisation and improvement of the desired crossbred population can only be efficient in situations where breeding programmes with well-defined breeding objectives are active. In most of the tropics, breeding objectives are not developed, especially for the smallholder farmers.

Discussion questions

- Crossbreeding programmes should be accompanied by measures ensuring the conservation of animal genetic resources. Describe programmes that can be set up to conserve indigenous animal genetic resources.
- The experiences at Kilifi Plantations led to wide acceptance of crossbred genotypes by farmers who did not consider their production environment when purchasing the crossbred genotypes. What information is needed and how can farmers use it to match crossbred genotypes to their production conditions?
- After purchasing animals (most of the time when in-calf) from Kilifi Plantations, farmers realised that to obtain calves with high genetic merit from these crossbred genotypes, the use of artificial insemination (AI) was necessary. AI is not readily available and when available, it is too expensive for them. Describe programmes that should be set up to supply the farmers, at low costs, with bulls that have high genetic merit. How can such programmes be organised and made to work at the village level?
- What is food security and what role might crossbreeding play in ensuring food security?
- There is still need for on-farm evaluation of different crossbred genotypes. This calls for development of simple recording systems that are workable and acceptable to the farmers. What are simple recording systems and what information do you think should be included in them?

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